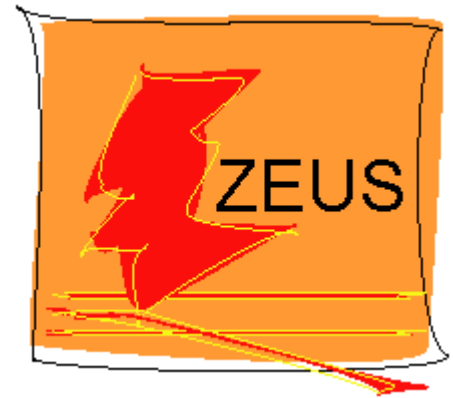VI Workshop on Particle Correlations and Femtoscopy

Kiev, September 14-18, 2010

ZEUS

# Measurements of inclusive and exclusive particle production at ZEUS

*Igor Kadenko,*
*Taras Shevchenko National University of Kyiv*
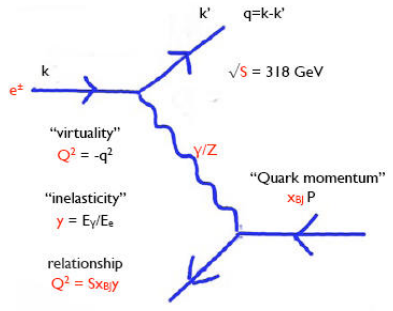*Department of Nuclear Physics*

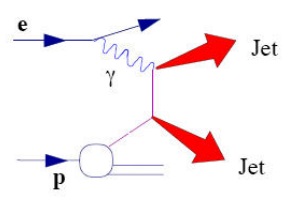*(on behalf of the ZEUS Collaboration)*

# Outline

- **Particle production in high energy electron proton scattering.**

- **Experimental setup: HERA accelerator and ZEUS detector.**

- **Charged particles production in:**
  - **deep inelastic scattering (DIS);**
  - **photo-production.**

- **Production of identified neutral particles.**

- **Exclusive production: di-pion diffractive electro-production.**

- **Conclusions.**

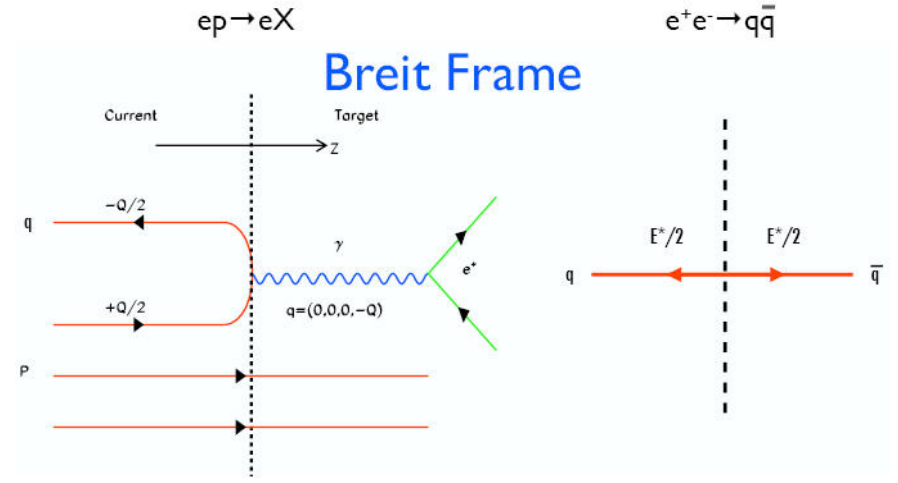# Particle production in high energy electron-proton scattering
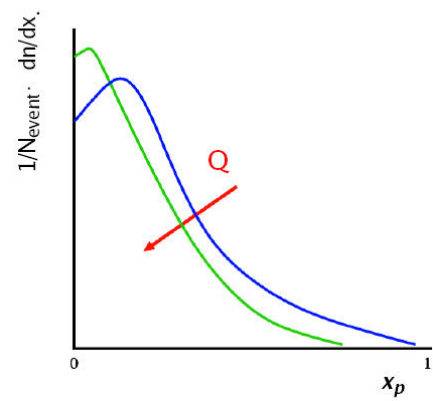
## DIS and Photoproduction

$q = k-k'$

$\sqrt{S} = 318$ GeV

"virtuality"
$Q^2 = -q^2$

$\gamma/Z$

"Quark momentum"
$x_{BJ} P$

"inelasticity"
$y = E_\gamma/E_e$

relationship
$Q^2 = Sx_{BJ}y$

DIS diagram

Dijet photoproduction

$Q^2 \approx 0$ GeV$^2$ Photoproduction
$Q^2 > 1$ GeV$^2$ Deep Inelastic Scattering

$ep \rightarrow eX$

### Breit Frame

$e^+e^- \rightarrow q\bar{q}$

Current

Target

$-Q/2$

$+Q/2$

$q = (0,0,0,-Q)$

$E^*/2$  $E^*/2$

Scaled momentum  $x_p = \dfrac{(2\,P_h)}{Q} = \dfrac{P_h}{E_{beam}}$

For  *ep*  and  *e⁺e⁻*

$P_h$ – momentum of charged particles in current region of the Breit frame.

With Q increasing
$dn/dx_p$ is softer,
i.e. more particles with smaller fraction of energy Q/2.

$1/N_{event} \cdot dn/dx$

Q

**Most of the interactions (~90%) are the photo production**

# Measurement of scaled momentum distributions $x_p$ as a test of QCD

QCD predictions for $x_p$ distributions:

- $f(x, Q^2) \otimes \sigma_{NLO} \otimes D(x_p, Q^2)$
- $D(x_p, Q^2)$ – fragmentation function (FF), which describes probability for a parton to fragment into a hadron carrying a given fraction of the parton's energy
- factorization theorem guarantees that FF are independent of the process

# The HERA Collider

- World's only *ep* collider, located at DESY in Hamburg
- In operation from 1992-2007

e⁻ ➡️ 🌟 ⬅️ p
27.5 GeV      920 GeV
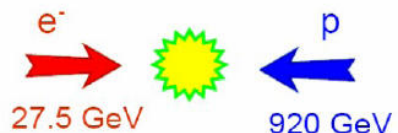
Center of mass energy:
$$\sqrt{s} = 318 \text{ GeV}$$

- Lepton beam longitudinally polarized in HERA-II running period (since 2002, P ≈ 30-40%)
- Two colliding experiments: H1 and ZEUS
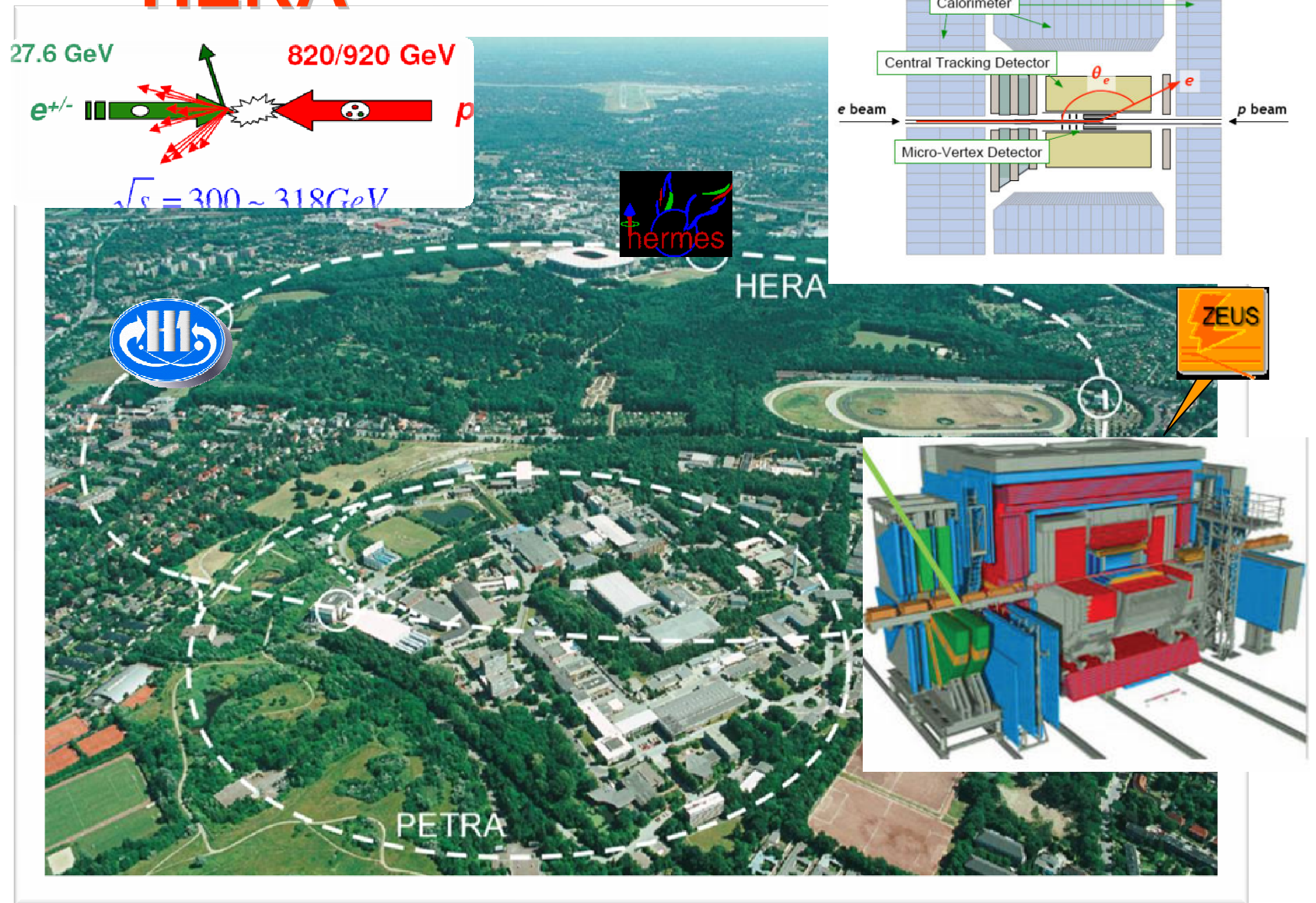- 0.5 fb⁻¹ of data collected by each experiment
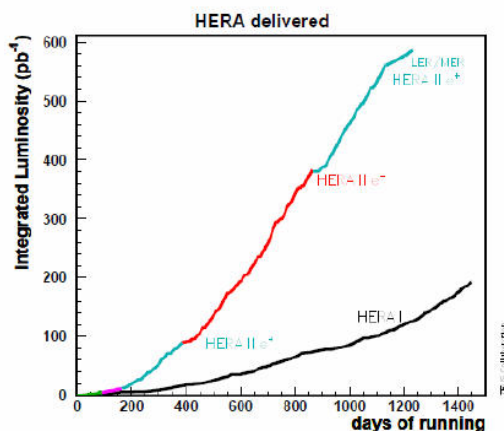


| $e^{\pm}$ | $p$ | $E_p$ | $\sqrt{s}$ |
|---|---|---|---|
| | | 820 | 301GeV |
| $E_e$=27.6 GeV | | 920 | 319GeV |
| | | 460 | 225GeV |
| | | 575 | 252GeV |

Different √s allows *direct measurement* of the different structure functions contributions at a given point in phase space.

**DATA sample:**
- ZEUS data: $\mathcal{L} \approx 0.5 \text{ fb}^{-1}$
- The data sample is dominated by 90% photoproduction, while 10% is Deep Inelastic Scattering

# HERA



27.6 GeV       820/920 GeV

$e^{+/-}$      $p$

$$\sqrt{s} = 300 \sim 318 GeV$$

Calorimeter

Central Tracking Detector    $\theta_e$    $e$

$e$ beam         $p$ beam

Micro-Vertex Detector
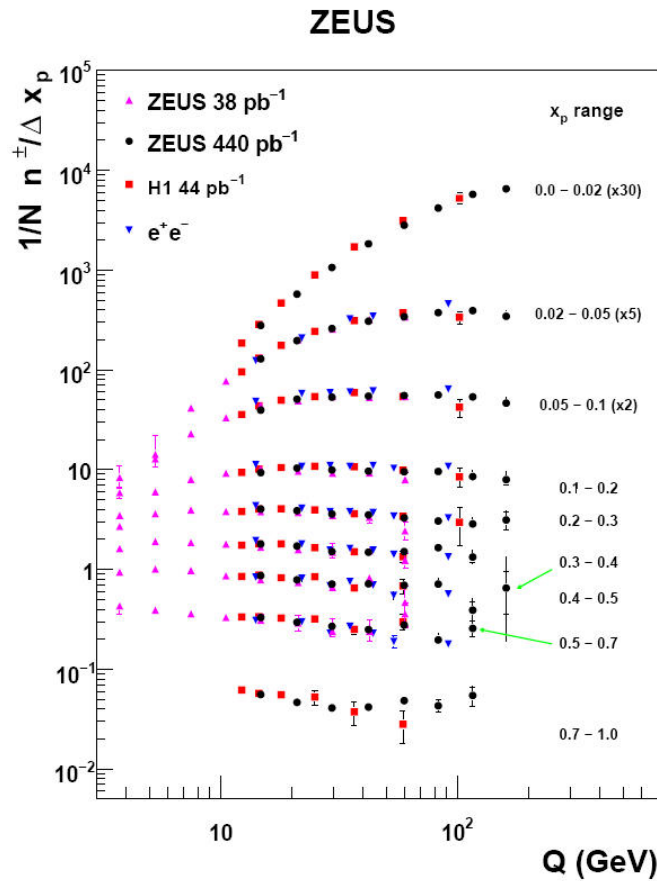
hermes

H1

ZEUS

HERA

PETRA

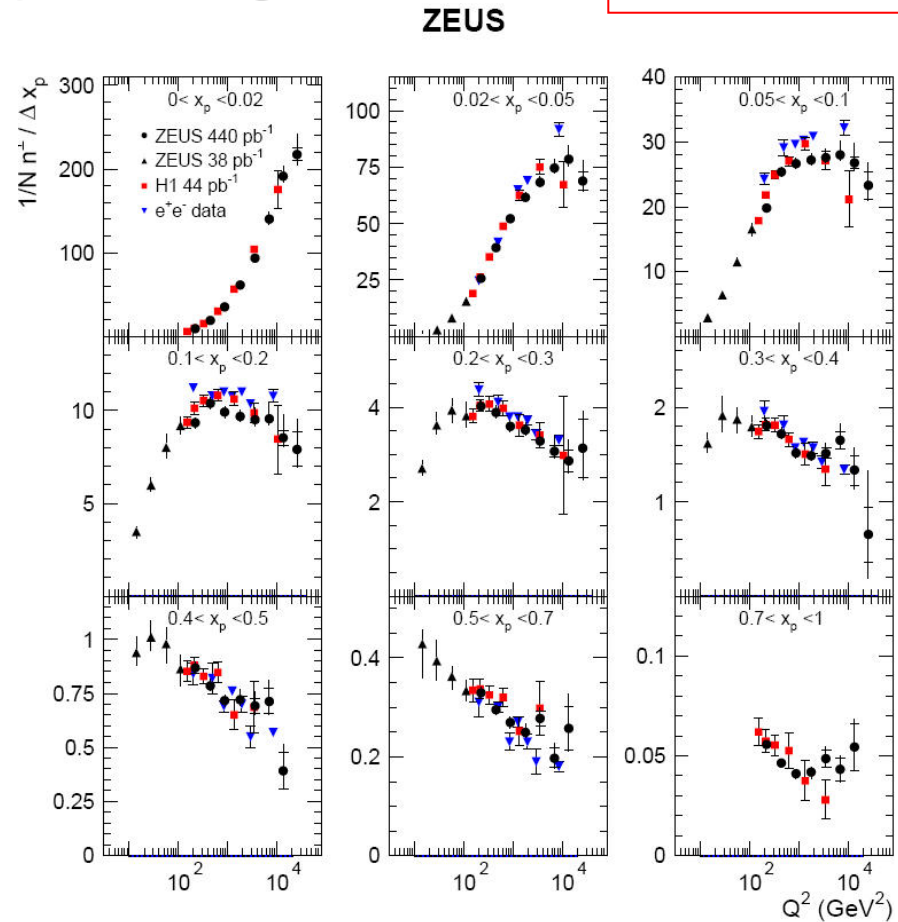# I. Charged particle production in neutral current DIS

- Tests of factorisation and the universality of fragmentation by

  - direct tests: Compare the same measurements (e.g. Fragmentation functions) from different experiments (Zeus, H1, CDF, OPAL, etc...) with each other.

  - Indirect tests: Compare a variety of measurements with the same theory (Monte Carlo, MLLA, NLO+FF). Monte Carlo and NLO Fragmentation function parameterisations fitted to $e^+e^-$ annihilation data. MLLA parameters taken from global fit to all data.

- Non DGLAP behaviour of parton dynamics

  - Go to area of phase space that is expected to be sensitive to DGLAP / BFKL / CCFM differences (low Q2, low x DIS) and compare data to different model predictions.
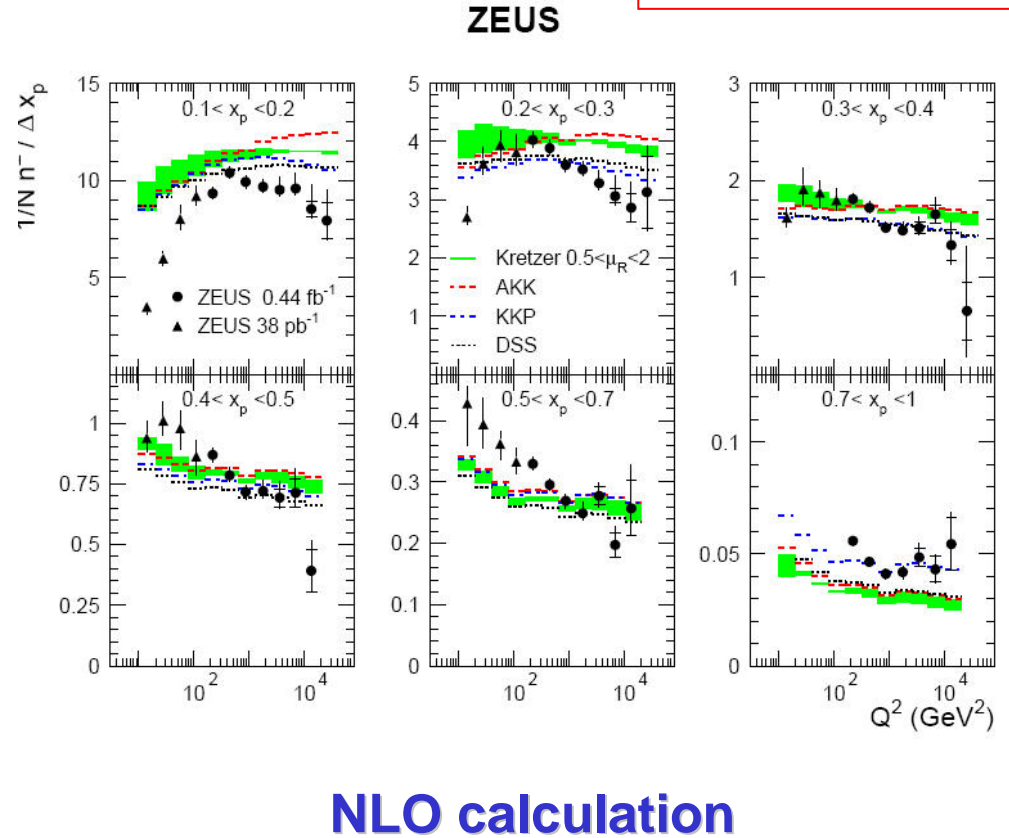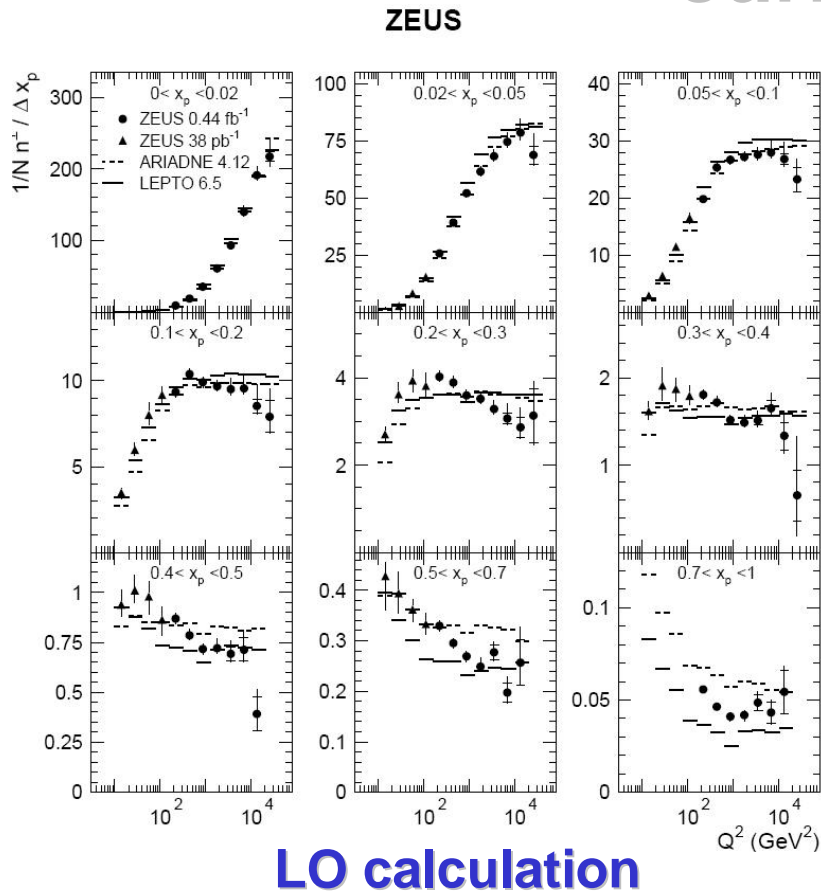
# I. Charged particle production in neutral current DIS

**The number of charged particles per event as a function of Q in $x_p$ bins**

**The number of charged particles per event as a function of $Q^2$ in $x_p$ bins**

# I. Charged particle production in neutral current DIS

DESY-09-229



**LO calculation**

**NLO calculation**

**The number of charged particles per event as a function of $Q^2$ in $x_p$ bins**

# I. Charged particle production in neutral current DIS

- In General results are found to support the concept of quark fragmentation universality. However, in detail, there exists some issues when comparing the data with theory.

- At low x DIS, the CDM model is found to provide a better description of parton dynamics indicating that the emission of partons in not strongly ordered in $k_T$.

# II. Scaled momentum distributions of charged particles for dijet photoproduction

DESY-09-059

## The Modified Leading Log Approximation (MLLA)

- All orders pQCD resummation.
- Analytical description of parton evolution.
- Predicts parton multiplicity and momenta.
- 2 free parameters in MLLA:
  - $Q_0$ - An self imposed cut-off energy scale.
  - $\Lambda_{\mathrm{eff}}$ - Absolute minimum cut-off of the theory.
- Predictions only physical with $Q_0 \geq \Lambda_{\mathrm{eff}} > \Lambda_{\mathrm{QCD}}$.
- Limiting spectrum defined such that, $Q_0 = \Lambda_{\mathrm{eff}}$.
- $\Lambda_{\mathrm{eff}}$ predicted to be universal.
- Assuming Local Parton Hadron Duality MLLA predictions are directly comparable to data.

## The MLLA + LPHD Theoretical Framework

### The Local Parton Hadron Duality (LPHD) Hypothesis

- Simple non-perturbative hypothesis.
- Assumes hadronisation is local and occurs at the end of the parton shower.
- Event topology is defined in the perturbative phase.
- Relates the observed hadron distributions to the calculated parton distributions via a single constant factor, $\kappa_{\mathrm{ch}}$.

$$O(x_1, x_2, \ldots)|_{\mathrm{hadrons}} = \kappa_{\mathrm{ch}} O(x_1, x_2, \ldots, \Lambda_{\mathrm{eff}})|_{\mathrm{partons}}$$

### What is $\kappa_{\mathrm{ch}}$ ?

- $\kappa_{\mathrm{ch}}$ is the ratio of the number of charged particles over the total number of partons produced during fragmentation.
- From isospin invariance, expect $\kappa_{\mathrm{ch}} \approx 2/3$
- 2 free parameters in MLLA + LPHD: $\Lambda_{\mathrm{eff}}$ and $\kappa_{\mathrm{ch}}$.

# II. Scaled momentum distributions of charged particles for dijet photoproduction

DESY-09-059

## Physics Motivation

### Investigating the limits of the MLLA

- $\Lambda_{\text{eff}}$ and $\kappa_{\text{ch}}$ have been measured using HERA II $\gamma P$ data collected using the ZEUS detector.
- The measurement was performed at various energy scales and within cones of various opening angles, $\theta_c$, around the jet axis.

### Is $\Lambda_{\text{eff}}$ universal?

- $\Lambda_{\text{eff}}$ previously measured for $ee$, $eP$ & $P\bar{P}$. Never for $\gamma P$.
- Is $\Lambda_{\text{eff}}$ independent of interaction type? $ee$, $eP$, $P\bar{P}$, $\gamma P$.
- Is $\Lambda_{\text{eff}}$ independent of $E_{\text{Jet}}$ and $\theta_c$, as predicted?
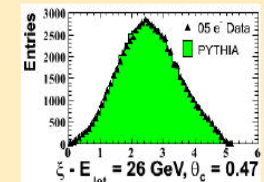
## Outline of analysis

- Select dijet photoproduction events from HERA II data.
- Measure scaled track momentum within jets, $x_p = \frac{P_{\text{track}}}{P_{\text{Jet}}}$.
- Plot scaled momentum distributions, $\xi = \ln\left(\frac{1}{x_p}\right)$, in bins of $E_{\text{jet}} = \frac{M_{2j}}{2}$ (the hard scale).

### Fitting $\xi$ distributions

- 2 methods:
  - MLLA + LPHD theory;
  - Gaussian around mean.
- $\Lambda_{\text{eff}}$ and $\kappa^{\text{ch}}$ extracted from fits.

### Sneak preview - a $\xi$ distr.



$\xi$ - $E_{\text{Jet}}$ = 26 GeV, $\theta_c$ = 0.47

# II. Scaled momentum distributions of charged particles for dijet photoproduction
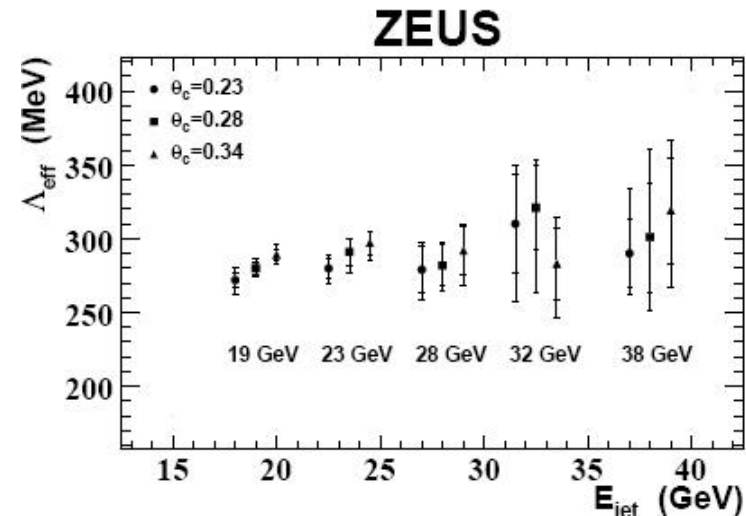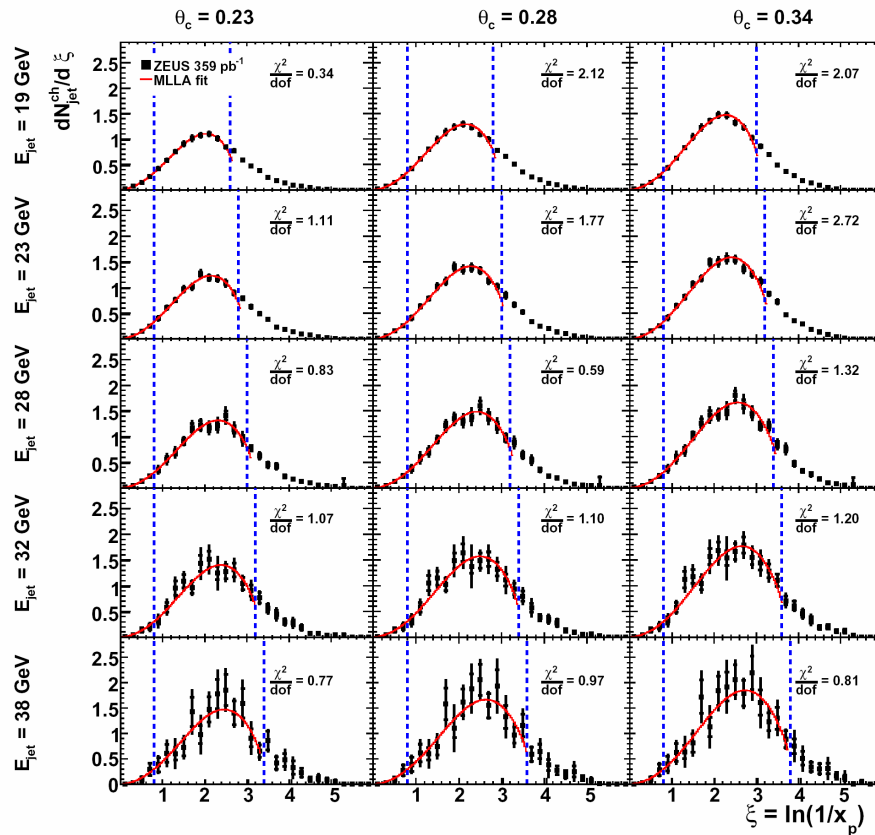


The ξ -distribution in five E_jet bins



Λ_eff extracted at five E_jet points

# II. Scaled momentum distributions of charged particles for dijet photoproduction

DESY-09-059

- Scaled momentum distributions have been measured in dijet events in HERA II $\gamma p$ data.
- $\Lambda_{\text{eff}}$ and $\kappa_{\text{ch}}$ have been extracted at energy scales from $19 \rightarrow 38$ GeV.

$$\Lambda_{\text{eff}} = 275 \pm 4\,(\text{stat.})^{+4}_{-8}\,(\text{syst.})\ \text{MeV}$$

$$\kappa_{\text{ch}} = 0.55 \pm 0.01\,(\text{stat.})^{+0.03}_{-0.02}\,(\text{syst.})^{+0.11}_{-0.09}\,(\text{theo.})$$

•The distributions are compared to predictions based on perturbative QCD carried out in the framework of the modified leading-logarithmic approximation (MLLA) and assuming local parton-hadron duality (LPHD)

# III. Scaled momentum distributions of identified particles, $K^0_s$ and $\Lambda$
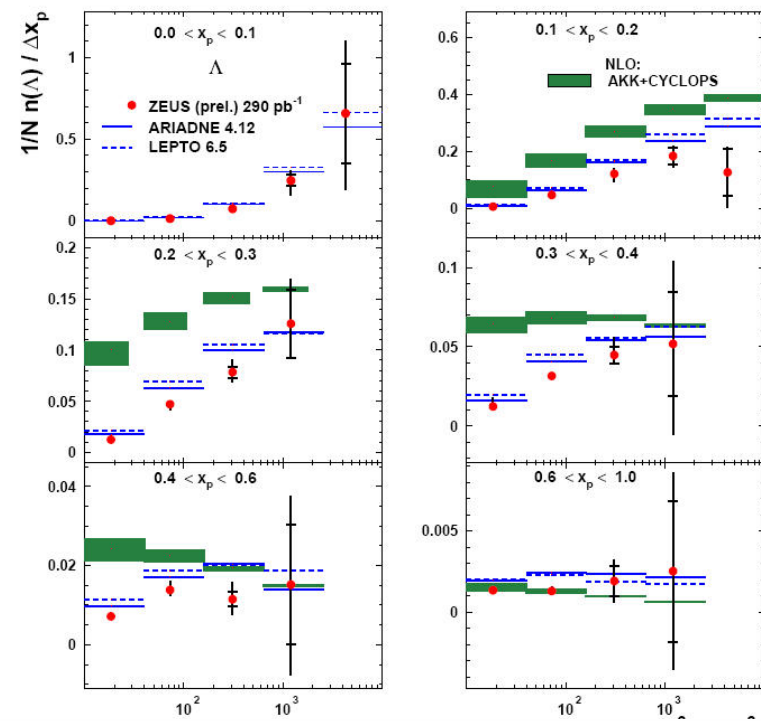
ZEUS-prel-10-013

**Scaled momentum distributions for $K^0_s$ vs. $Q^2$ in different regions of $x_p$**
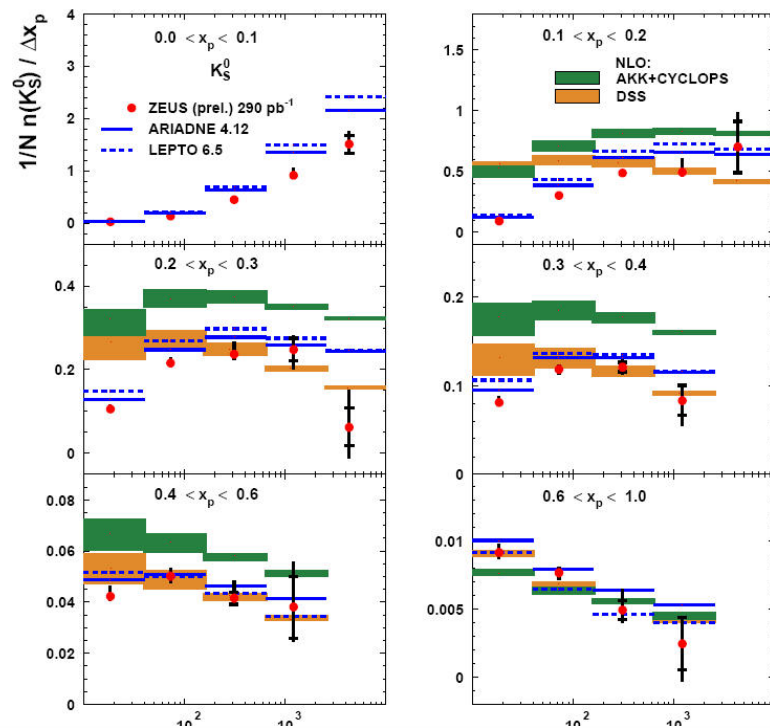
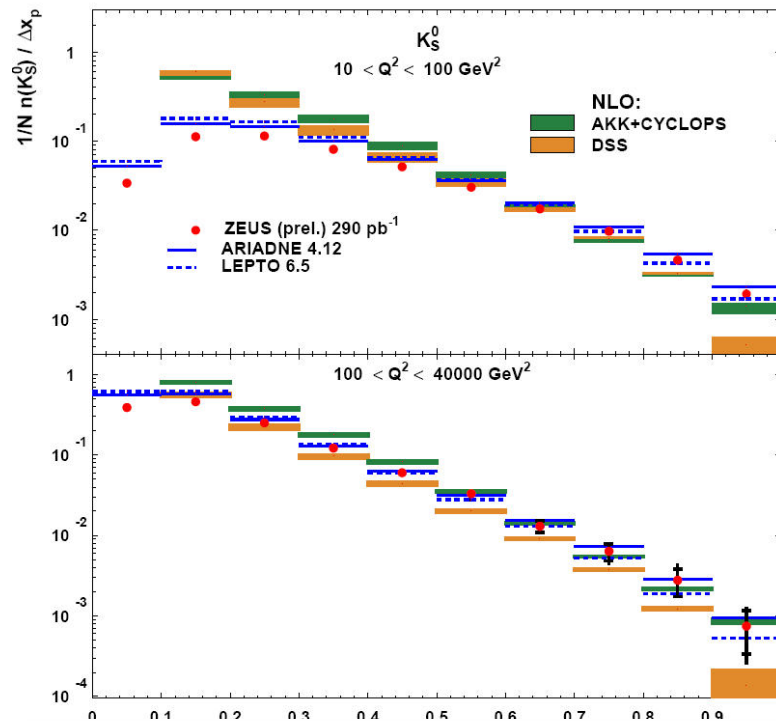**Scaled momentum distributions for $\Lambda$ vs $Q^2$ in different regions of $x_p$**



- Scaling vilation is observed
- QCD NLO predictions describe the data only in certain regions of the phase space
- LO predictions : ARIADNE (CDM) and LEPTO (MEPS) describe the data in full phase space
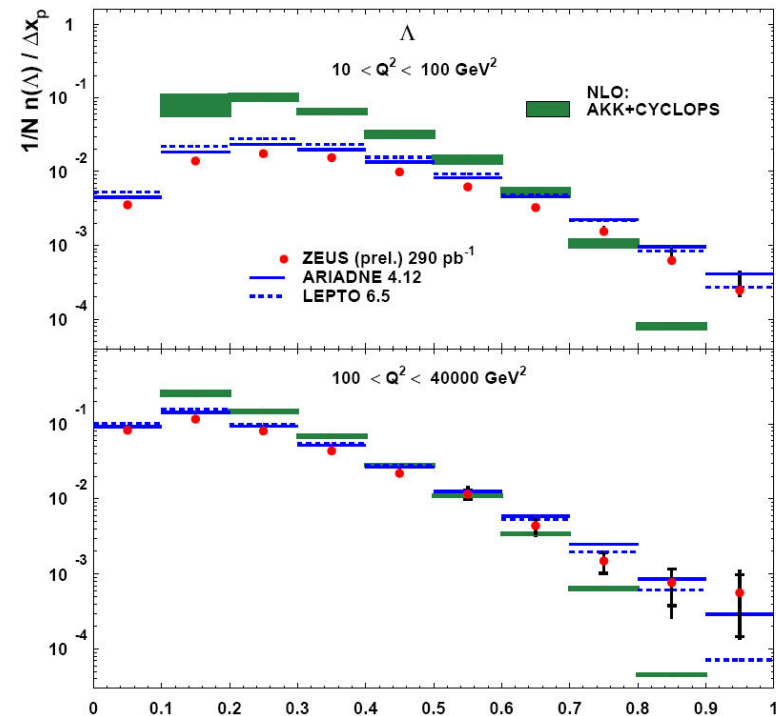
# III. Scaled momentum distributions of identified particles, $K^0_s$ and $\Lambda$

ZEUS-prel-10-013

**Scaled momentum distributions for $K^0_s$ vs. $x_p$ in different regions of $Q^2$**

**Scaled momentum distributions for $\Lambda$ vs. $x_p$ in different regions of $Q^2$**
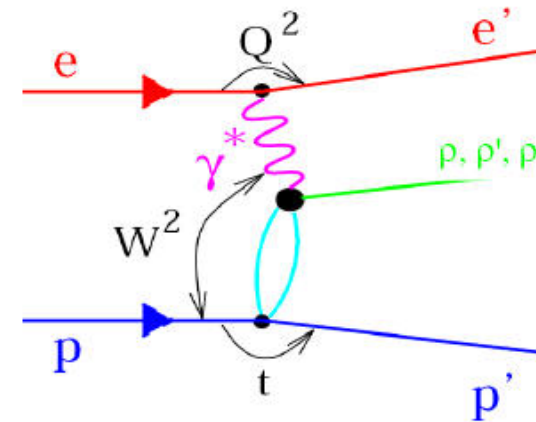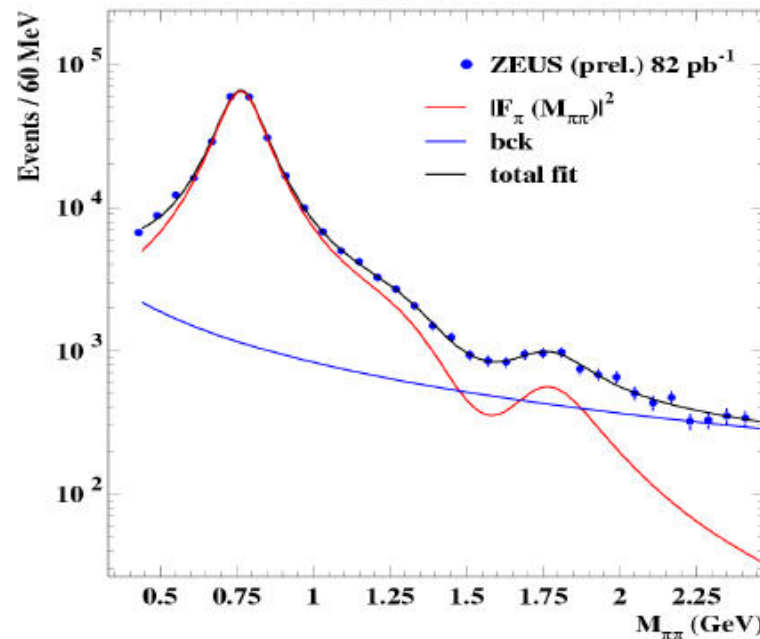


- QCD predictions describe the data in the high $Q^2$ region and high $x_p$
- LO MC gives a reasonable description of the data in full phase space

# IV. Dipion diffractive electro-production

## Exclusive dipion production

* data 1998-2000 sample (82 pb$^{-1}$)
* two pions in the detector
* electron in the detector



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- ● ZEUS (prel.) 82 pb$^{-1}$
- — $|F_\pi (M_{\pi\pi})|^2$
- — bck
- — total fit

$$\frac{dN(M_{\pi\pi})}{dM_{\pi\pi}} = N\left[ |F_\pi(M_{\pi\pi})|^2 + \frac{B}{M_{\pi\pi}^n} \right]$$

$$F_\pi(M_{\pi\pi}) = \frac{BW(\rho)+\beta BW(\rho')+\gamma BW(\rho'')}{1+\beta+\gamma}$$
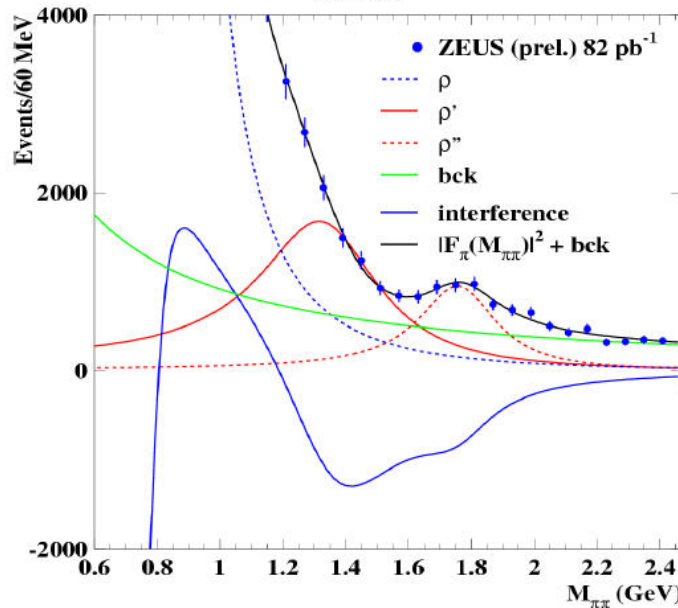
Relative amplitudes

Pion electromagnetic form factor

- ● $F_\pi(M_{\pi\pi})$ is the pion electro-magnetic form factor given by contributions from vector resonances $\rho$, $\rho'$ and $\rho''$.

## Data are good described by pion form factor

# IV. Dipion diffractive electro-production

### Fit of the resonances
### ZEUS

$$F_\pi(M_{\pi\pi}) = \frac{BW(\rho)+\beta BW(\rho')+\gamma BW(\rho'')}{1+\beta+\gamma}$$

Breit-Wigner depends on mass and width



| Parameter | ZEUS (prel.) | PDG |
|---|---|---|
| $M_\rho$ (MeV) | $772 \pm 2^{+2}_{-1}$ | $775.49 \pm 0.34$ |
| $\Gamma_\rho$ (MeV) | $155 \pm 5 \pm 2$ | $149.4 \pm 1.0$ |
| $\beta$ | $-0.27 \pm 0.02 \pm 0.02$ | |
| $M_{\rho'}$ (MeV) | $1360 \pm 20^{+20}_{-30}$ | $1465 \pm 25$ |
| $\Gamma_{\rho'}$ (MeV) | $460 \pm 30^{+40}_{-45}$ | $400 \pm 60$ |
| $\gamma$ | $0.10 \pm 0.02^{+0.02}_{-0.01}$ | |
| $M_{\rho''}$ (MeV) | $1770 \pm 20^{+15}_{-20}$ | $1720 \pm 20$ |
| $\Gamma_{\rho''}$ (MeV) | $310 \pm 30^{+25}_{-35}$ | $250 \pm 100$ |

**Good agreement between ZEUS (preliminary) results and PDG.
Reasonable values of the relative amplitudes are obtained.**

# IV. Dipion diffractive electro-production

$$R' = \sigma(\rho') \cdot Br(\rho' \to \pi\pi)/\sigma(\rho)$$



**ZEUS**

ZEUS (prel.) 82 pb⁻¹

- $\rho'/\rho$
- $\rho''/\rho$
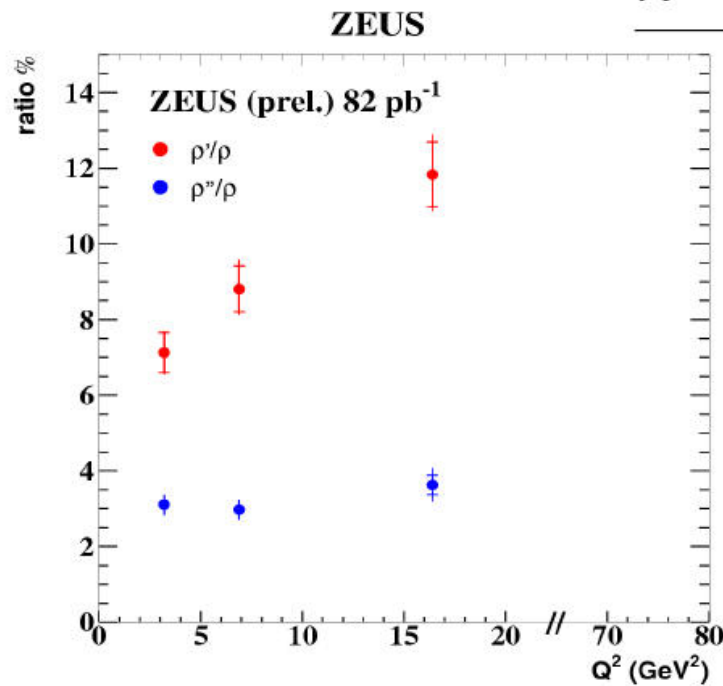
- rho'/rho increases with $Q^2$
- rho"/rho constant with $Q^2$

The **anomalous** behavior of $V'(2S)/V(1S)$ production ratio with $Q^2$ was predicted in works of J. Nemchik, B. Kopeliovich, N. Nikolaev, B. Zakharov, (see hep-ph/9605208 and referencies therein).

# Conclusions

- **Charged particle spectra have been measured in DIS and photoproduction at HERA. In General results are found to support the concept of quark fragmentation universality. However, in detail, there exists some issues when comparing the data with theory.**

- **Many new high statistics measurements of exclusive Vector Mesons at HERA. The measurements allow us to study the transition from the soft to hard regime. The perturbative QCD expectations in general are compatible with the data. The different models describe main features, but differ in some details. The measurements provide new insight into the proton structure with a high sensitivity to gluon density, skewing effects and GPDs.**

- **The measured in LAB and the Breit frame production cross sections of neutral strange hadrons in general are in good agreement with predictions of two MC: MEPS and CDM when applying model parameters with lambda_s = 0.286 as used at LEP.**